European Society of Endodontology position statement: Management of deep caries and the exposed pulp

Duncan, H F ; Galler, K M ; Tomson, P L ; Simon, S ; El-Karim, I ; Kundzina, R ; Krastl, G ; Dammaschke, T ; Fransson, H ; Markvart, M ; Zehnder, M ; Bjørndal, L

Abstract: This position statement on the management of deep caries and the exposed pulp represents the consensus of an expert committee, convened by the European Society of Endodontology (ESE). Preserving the pulp in a healthy state with sustained vitality, preventing apical periodontitis and developing minimally invasive biologically based therapies are key themes within contemporary clinical endodontics. The aim of this statement was to summarize current best evidence on the diagnosis and classification of deep caries and caries-induced pulpal disease, as well as indicating appropriate clinical management strategies for avoiding and treating pulp exposure in permanent teeth with deep or extremely deep caries. In presenting these findings, areas of controversy, low-quality evidence and uncertainties are highlighted, prior to recommendations for each area of interest. A recently published review article provides more detailed information and was the basis for this position statement (Bjørndal et al. 2019, International Endodontic Journal, doi:10.1111/iej.13128). The intention of this position statement is to provide the practitioner with relevant clinical guidance in this rapidly developing area. An update will be provided within 5 years as further evidence emerges.

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EUROPEAN SOCIETY OF ENDODONTOLOGY POSITION STATEMENT: MANAGEMENT OF DEEP CARIES AND THE EXPOSED PULP

European Society of Endodontology (ESE) position stement developed by: Duncan HF[1], Galler K[2], Tomson PL[3], Simon S[4], El-Karim I[5], Kundzina R[6], Krastl G[7], Dammaschke T[8], Zehnder M[9], Bjørndal LB[10]

Further additions comments and consensus by: ESE Executive Board

Affiliations: [1]Division of Restorative Dentistry, Dublin Dental University Hosptal, Trinity College Dublin, University of Dublin, Ireland
[2]
[3]School of Dentistry, University of Birmingham, St Chads Queensway, Birmingham, UK
[4]Paris Diderot University, Paris 7, Paris, France
[5]
[6]
[7]
[8]
[9]
[10]Cariology and Endodontics, Faculty of Health Sciences, University of Copenhagen, Nørre Allé 20, Copenhagen, Denmark

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Correspondence: Dummer PMH, CEO of the European Society of Endodontology, Postboks 1237 Vika, 0110 Oslo, Norway. (e-mail: ceo@e-s-e.eu).

ESE-APPROVED DEFINITIONS AND TERMINOLOGY/GLOSSARY

Deep caries: Radiographic evidence of caries reaching the inner third or inner quarter of dentine with a risk of pulp exposure.

Extremely deep caries: Radiographic evidence of caries penetrating the entire thickness of the dentine with certain pulp exposure.

Selective caries removal:

Selective removal to soft dentine: Removal of peripheral carious dentine to hard dentine, leaving soft dentine only on the pulpal aspect of the cavity.

Selective removal to firm dentine: Removal of peripheral carious dentine to hard dentine, leaving firm/leathery dentine only on the pulpal aspect of the cavity. The residual dentine should be resistant to hand excavation.

Non-selective caries removal: Complete removal of soft and firm carious dentine from the periphery and central aspects of the cavity until hard dentine reached.

Vital pulp treatment (VPT): Minimally invasive strategies aimed at maintaining the vitality of the pulp.

Indirect pulp capping: Application of a biomaterial onto a thin dentine barrier in a one-stage selective caries removal technique.

Stepwise excavation: Application of a biomaterial onto a thin dentine barrier in a two-stage selective caries removal technique, with re-entry after 6-12 months. First stage involves selective caries removal to soft dentine and second stage to firm dentine.

Direct pulp capping: Application of a biomaterial directly onto the exposed pulp.

Class I: No preoperative presence of a deep carious lesion. Pulp exposure judged clinically to be through sound dentine.

Class II: Preoperative presence of a deep carious lesion. Pulp exposure judged clinically to be through a zone of potential bacterial contamination. Enhanced operative protocol recommended.

Mini-pulpotomy: Removal of the superficial layer of the coronal pulp after pulp exposure, application of a biomaterial directly onto the exposed pulp tissue.

Partial pulpotomy: Removal of the coronal 2-4 mm of pulp tissue after exposure, and application of a biomaterial directly onto the exposed pulp tissue.

Full pulpotomy: Complete removal of the coronal pulp and application of a biomaterial directly onto the pulp tissue at the level of the root canal orifices.

Pulpectomy: Total removal of the pulp from the root canal system followed by root canal treatment.

ABSTRACT

This position statement on the management of deep caries and the exposed pulp represents the work of an expert committee, convened by the European Society of Endodontology (ESE), supported by consensus. The importance of preserving pulp vitality, preventing apical periodontitis and developing minimally invasive biologically based therapies are key themes within modern clinical endodontics. The aim of this statement is to summarise current best evidence on the diagnosis and classification of caries-induced pulpal disease, as well as indicating appropriate clinical management strategies for avoiding and treating pulp exposure in permanent teeth with deep caries. In presenting the findings, areas of controversy, low quality evidence and uncertainly are highlighted, prior to a series of short recommendations being made for each area of interest. A recently published review article provides information that is more detailed, and was the basis for this position statement (Bjørndal *et al*. 2018, International Endodontic Journal). While, it is hoped that this evidence-based document will provide the practitioner with relevant clinical guidance in this rapidly developing area, it is likely that this position statement will be a relatively 'fluid' document, which will be updated within 4 years as further evidence emerges.

INTRODUCTION

The destructive nature of conventional dental treatment and concerns of overtreatment and the 'restorative cycle', have led the profession to promote minimally invasive biologically based treatment strategies. This has resulted in a shift in the management of deep caries from non-selective (complete) removal to selective (partial) removal, reducing the risk of pulp exposure (Innes *et al*. 2016). Modern management strategies for the cariously exposed pulp have seen the re-emergence and extension of vital pulp treatment (VPT) techniques such as partial and complete pulpotomy. As the maintenance of pulp vitality and the prevention of apical periodontitis are core values in Endodontics, these developments are of fundamental importance to the members of the European Society of Endodontology (ESE). This position statement reflects the current views of the society on these issues. It provides the practitioner with recommendations regarding the diagnosis and treatment of deep caries and the exposed pulp in permanent teeth based on current knowledge and literature.

This statement limits itself to the management of deep caries, further subdivided into two radiographic categories, deep and extremely deep. This categorisation aims to quantify the risk of pulp exposure*,* as well as potentially highlight a threshold for the onset of more severe pulp inflammation (Reeves & Stanley 1966). Deep carious lesion has radiographic evidence of caries reaching the inner third or quarter of dentine, but still with a visible zone of translucent dentine between the carious dentine and the pulp, while an extremely deep carious lesion penetrates the entire thickness of the dentine (Bjørndal 2018, Bjørndal *et al*. 2018). Caries is a microbial biofilm induced-disease, driven by a supply of fermentable carbohydrates (Nyvad *et al.* 2013, Pitts *et al*. 2017). The resulting ecological shift creates an acidogenic, cariogenic niche, which breaks down dental hard tissue to form a cavity (Schwendicke *et al*. 2016). The global prevalence of caries remains high; however, the burden of untreated caries is shifting from children to adults (Bernabé & Sheiham 2014, Kassebaum *et al*. 2015). Caries also has a greater prevalence in patients from disadvantaged social groups (Sengupta *et al*. 2017, Costa *et al.* 2018) and is costly to manage in industrialised and non-industrialised countries (Peterson 2008, Listl *et al.* 2015). The aetiology of caries; however, offers opportunities to manage the condition by modifying diet, improving oral hygiene and application of fluoride (O'Mullane *et al.* 2016). Furthermore, if the biofilm is isolated from its nutrient supply, the microbial ecology changes, this forms the basis of non-selective caries

removal techniques in which some of the bacteria remain after treatment (Bjørndal *et al*. 1997, Banarjee *et al.* 2017).

During the carious process, microbial penetration and release of bacterial by-products migrate down the dentinal tubules leading to an inflammatory response of the pulp. Odontoblasts, dendritic cells and pulpal fibroblasts (Farges *et al*. 2015) mediate this process. Initially, a hyperaemic response occurs with a decline in cell numbers, flattening of the odontoblast cell bodies (Bjørndal 2018) and immigration of lymphocytes and plasma cells to the affected area (Ricucci *et al*. 2014). Although pulpitis will accompany the carious process throughout its progression, it is not until the carious infected demineralized dentine is close to the pulp, that the inflammatory response becomes severe and there is a risk of bacteria entering the pulp (Reeves & Stanley 1966, Mjör & Tronstad 1972). However, pulp tissue has an innate ability to repair if the challenge is removed and the tooth is suitably restored (Mjör & Tronstad 1974). Preservation of pulp vitality maintains the pulp's developmental (primary and secondary dentinogenesis), defensive (tertiary dentinogenesis) and proprioceptive response. Appropriate caries management within VPT aims to remove the microbial irritation and prevent new bacterial insult by placing a sealing dental biomaterial to protect exposed dentine and pulp from external stimuli. Therapeutically, VPT is quicker, less technically demanding and has less unwanted effects such as discoloration, fracture or residual periapical inflammation than root canal treatment (RCT). Conversely, it can be argued that VPT and management of deep carious lesions is very sensitive to ongoing bacterial contamination making the technique ´biologically demanding´, often requiring magnification and expertise to treat. Thus, the overarching aims of caries management and VPT are to manage bacterial contamination, arrest caries progression, stimulate tertiary dentine formation, and promote pulpal healing as well as restoring the cavity to create a durable seal for long-term preservation of a vital, symptom-free and functional tooth.

EVIDENCED-BASED RECOMMENDATIONS

Classifications of disease severity to guide decision making in VPT

Multi-centre prospective studies investigating the management of deep caries in adult patients have focused on the extent and depth of carious lesions radiographically as the principle inclusion criterion (Bjørndal *et al*. 2010, 2017). A detailed radiographic description of deep caries, equal to three quarters of the dentine with a well-defined radio-dense zone between the caries and the pulp, was included; however, the pulpal symptomatology was less-detailed (Bjørndal *et al*. 2010, 2017). A recent prospective study, investigating indirect pulp treatment (IPT) in deep caries, included a pulpal classification as an inclusion criterion and noted the importance of pain severity in outcome (Hashem *et al*. 2015). On a similar theme, an International Endodontic Journal editorial described a new classification system for pulpitis linking symptoms rather than radiographic depth to management in VPT (Wolters *et al*. 2017). The American Association of Endodontists (AAE) endorsed the currently accepted classification of pulpal disease in 2013, describing pulpitis as either reversible or irreversible depending on clinical signs and symptoms. The symptoms of reversible pulpitis range from no complaint to a sharp pain sensation with hot/cold stimuli and no tenderness to percussion; notably, the symptoms should resolve after removal of the stimulus. Spontaneous, radiating pain and sleep disturbance tend to indicate irreversible pulpitis (Dummer *et al*. 1980) with lingering pain after removal of the stimulus. Clinical judgement is required; however, as irreversible pulpitis may be symptomless in anywhere between 14-60 % of cases (Seltzer *et al*. 1963, Michaelson & Holland 2002).

Although reversible and irreversible pulpitis may correlate with histological features (Ricucci *et al*. 2014), the decision to call a pulp reversibly inflamed does not determine the actual potential of the inflamed tissue to repair. Therefore, it is critical that teeth undergoing less invasive carious removal strategies, selective caries removal, IPC, pulp capping or pulpotomy after pulpal exposure are monitored postoperatively to ensure continuing pulpal vitality. With the development of pulpotomy interventions, aimed at permanently maintaining part of the pulp in teeth with signs and symptoms of irreversible pulpitis (Simon *et al*. 2013, Taha & Khazali 2017, Taha *et al*. 2017, Qudeimat *et al*. 2017), there have been calls to consider new more representative ways to classify pulpitis (Hashem *et al*. 2015, Wolters *et al*. 2017).

Recommendation: Several factors influence pulpal status, a knowledge of which is critical for the success of VPT strategies in the presence or absence of pulpal exposure. Caries depth radiographically as well as clinical indicators of activity (e.g. progression rate, colour, symptoms), should be used to assist clinical decision-making after history, examination and special tests. The currently accepted diagnostic terms, reversible and irreversible pulpitis, remain useful but will require revision going forward.

How should we diagnose the inflammatory state of the pulp?

The outcome of VPT is dependent on the inflammatory state of the pulp, with carious exposures generally having a less favourable outcome compared with traumatic exposures (Al-Hiyasat *et al*. 2006); however, the current methods of accurately ascertaining the level of pulpitis are poor. Assessment should begin with an accurate pain history, detailing response to temperature, spontaneity of pain, sleep disturbance and be supplemented with a through clinical and radiographic examination to obtain a provisional diagnosis. It should be borne in mind that a significant number of pulps become necrotic asymptomatically (Seltzer *et al.* 1963, Michaelson & Holland 2002) and therefore pulp sensibility testing should supplement the history and examination. Thermal and electric pulp testing (EPT) remain the appropriate clinical tests to use, but are crude and non-quantitative being subject to false positive and negative readings. Cold testing has greater specificity and sensitivity compared with heat, although has only moderate accuracy compared with experimental techniques principally used after trauma (not caries), including pulse oximetry and laser Doppler flowmetry (Manikar & Kim 2017). In general, the colder the stimuli the better with carbon dioxide, tetrafluoroethane and commercial products such as Endo-Frost (Coltene/Whaledent, Langenau, Switzerland) diagnostically superior to ice or ethyl chloride in determining pulpal health (Fuss *et al*. 1986, Alghaithy & Qualtrough 2017). Heat mimics the patient's symptoms and may remain useful in the diagnosis of pulpitis; however, in general has low accuracy (Manikar & Kim 2018). Pain to cold stimuli remains the main symptom of acute forms of pulpitis that make patients seek an emergency dental visit (Recehnberg et al. PMID 27234432). These diagnostic methods are subjective and relatively crude only providing clinical guidance. Traditionally, these methods were not believed to reflect the true

histopathological status of the pulp (Garfunkel *et al.* 1973, Dummer *et al*. 1980). A recent histological study contradicted this by demonstrating a strong correlation between histology and the signs and symptoms of reversible/irreversible pulpitis (Ricucci *et al*. 2014); however, the latter study neither examined reparative responses or outcomes in relation to VPT, nor used teeth with inconclusive history and clinical test results as controls.

All current techniques are limited both in their capacity to establish the threshold of reversible and irreversible pulpitis and to determine the link between inflammatory status and healing potential of the affected tissue. As a result, the development new pulp sensibility tests and chairside assays of disease biomarkers as potential prognostic indicators should be a focus for translational development (Swedish Council on Health Technology Assessment 2010, Ballal *et al*. 2017, Rechenberg *et al*. 2018). In the absence of clinically available molecular tests of inflammation, the level of pulp bleeding only provides a crude measure of inflammation (Matsuo *et al.* 1996), but can be weakly recommended to supplement other information in cases of pulp exposure.

***Recommendation*:** A detailed pain history and clinical examination supplemented with a high quality periapical radiograph and pulp sensibility testing using low temperature thermal testing in combination with EPT.

How should we manage deep caries to avoid pulp exposure?

The indications for one stage selective carious removal and two-stage stepwise excavation or IPC are an asymptomatic tooth, which responds within normal limits to pulp sensibility testing or a tooth with signs and symptoms indicative of reversible pulpitis. There is no evidence to suggest that selective carious tissue removal or IPC are effective treatments in teeth with symptoms of irreversible pulpitis. Equally, non-selective (complete) carious removal is no longer regarded the treatment of choice in deep carious lesions, with recent consensus considering it overtreatment (Schwendicke *et al*. 2016).

In asymptomatic teeth or teeth with signs and symptoms of reversible pulpitis, exposure of the pulp should be avoided (if possible) in a less invasive carious removal strategy such as stepwise excavation or one stage selective removal procedure (Maltz *et al*. 2012, Bjørndal *et al*. 2017). These approaches have demonstrated success up to 90%, defined as the

absence of clinical symptoms and maintenance of pulp vitality, over 3 and 5 year follow up (Maltz *et al*. 2012, Bjørndal *et al*. 2017). Less invasive carious tissue removal techniques are generally carried out using sterile round burs and excavators (Maltz *et al*. 2012, Bjørndal *et al*. 2017); however, other self-limiting chemo-mechanical methods using products such as Carisolv gel (Carisolv, Rubicon Lifesciences), have been advocated to improve pulp survival over traditional rotary techniques (Ali *et al*. 2018). Selective carious removal to soft or firm dentine can be carried out in one-visit (Maltz *et al.* 2012) or in two-visits as a stepwise excavation technique (Bjørndal *et al*. 2017). Both techniques appear effective in reducing the risk of pulp exposure (Schwendicke *et al*. 2016) with advocates of single-visit carious removal suggesting that re-entry is unnecessary (Maltz *et al*. 2012), while supporters of stepwise techniques highlight that shrinkage of residual soft dentine will lead to a defective restoration without re-entry (Bjørndal 2018).

Regardless of the carious removal technique employed, carious tissue should be removed from the periphery of the cavity to hard dentine (i.e. non-selective removal), leaving soft or leathery dentine only on the pulpal aspect of the cavity. As residual dentine thickness over the pulp cannot be accurately assessed clinically the use of a biologically-based biomaterial, ideally a hydraulic calcium silicate or alternatively a glass ionomer cement, should be routinely applied to the dentine barrier prior to restoration with a definitive resin-based composite restoration (Hashem *et al*. 2015, 2018). The maintenance of pulp vitality should be confirmed by pulp sensibility testing. Exclusion criteria include teeth exhibiting spontaneous or constant pain, an non-restorable crown, a heightened or lingering response to pulp sensibility testing or a periapical lesion; these will have reduced prognosis and are not suitable candidates for selective caries removal (Bjørndal *et al*. 2010, Swedish Council on Health Technology Assessment 2010). From a practical perspective, it is beneficial during selective caries removal that the tooth is isolated with rubber dam, sterile instruments are used, the dentine is handled carefully and a suitable definitive restoration is placed to prevent further micro-leakage. Magnification should ideally be used throughout.

Recommendation: Selective carious tissue removal (one-stage or two-stage, stepwise technique) and avoidance of exposure are advocated in asymptomatic teeth or in teeth with signs and symptoms of reversible pulpitis in well-defined deep carious lesion reaching the pulpal quarter, but with a clear zone of dentine separating the carious lesion from the pulp.

A calcium silicate material or glass ionomer should be placed over the deep dentine in both one or two-stage procedures. Current evidence does not indicate a preference for one material over the other.

How should we manage carious pulp exposure?

Treatment options after carious pulp exposure include direct pulp capping and pulpotomy (mini, partial and full)**.** In general, pulp preservation is only advocated in asymptomatic teeth or teeth with signs and symptoms of reversible pulpitis, in these cases, as previously discussed, pulp exposure should ideally be avoided in a selective carious removal strategy (Bjørndal *et al*. 2017). These recommendations are based on pulp exposure being a negative prognostic factor in deep carious lesions (Bjørndal *et al*. 2010, Schwendicke *et al*. 2016). Several recent studies have highlighted comparable success after non-selective (complete) carious removal, pulp exposure and a VPT procedure involving operating microscope (Bogen *et al*. 2009, Marques et al. 2015) and/or the use of a disinfection agent (Kundzina *et al*. 2017). These studies all used hydraulic calcium silicate cements (not calcium hydroxide) in an enhanced class II protocol, which should include magnification, and a disinfecting solution rather than saline (Bogen *et al*. 2009). Operator skill and experience may also be an important, if not independently tested, variable determining the success of VPT.

Nevertheless, this research emphasizes that pulp capping of deep carious lesions can be successfully carried out, if an enhanced treatment protocol is followed (Bogen *et al*. 2009, Mente *et al*. 2014, Marques *et al*. 2015, Kundzina *et al*. 2017). This may help to explain the difference between these studies and the relatively low success of a classic pulp capping protocol examined both retrospectively (Barthel *et al*. 2000) and prospectively in deep carious lesions (Bjørndal *et al*. 2010). Notably, high-quality clinical research trials comparing these interventions are lacking and as a result it remains to be seen if these recent promising results can be replicated in a primary care setting. Furthermore, for dentists competent in handling pulp tissues, non-selective caries removal and pulp exposure can offer an opportunity to assess pulp damage, the presence of necrosis in the pulp chamber, the level of pulp bleeding and the true extent of the carious destruction.

The maintenance of pulp vitality should be confirmed preoperatively by pulp sensibility testing and intraoperatively by presence of vital tissue after exposure. Exclusion

criteria may alter in the future; however, teeth exhibiting spontaneous or constant pain, an unrestorable crown, a periapical lesion, continuous uncontrollable bleeding or the presence of necrotic tissue in the pulp chamber are generally not predictable candidates for pulp capping or pulpotomy (Bjørndal *et al*. 2010, Swedish Council on Health Technology Assessment 2010). Recent evidence has accumulated; however, which demonstrates success of full pulpotomy after one year to range between 75-95%, even in the teeth with signs and symptoms indicative of irreversible pulpitis (Asgary & Eghbal 2013, Asgary *et al.* 2015, Asgary *et al*. 2017, Galani *et al*. 2017, Linsuwanont *et al*. 2017, Qudeimat *et al*. 2017, Taha *et al.* 2017, Asgary *et al*. 2018). Notably, these success rates are difficult to compare with other VPT techniques, as the maintenance of pulp vitality cannot be verified by pulp sensibility testing. The potential of full pulpotomy to treat teeth with signs and symptoms of irreversible pulpitis is clear and although the evidence is preliminary, it indicates that an extension of traditional concepts of pulpectomy in these cases is likely in the future.

Clinically, it is essential during the VPT procedure that the tooth is isolated prior to pulpal exposure with rubber dam. Ideally, magnification should be used throughout the procedure to ensure removal of all infected dentine. The damaged tissue can be treated with the direct application of the capping material to the exposed pulp (pulp capping, class II), or removal of the surface of the exposed pulp (mini-pulpotomy) and removal of the coronal 2-4 mm of pulp tissue (partial pulpotomy). Some degree of pulp tissue removal may be preferable in carious exposures to aid physical removal of the biofilm and superficial inflamed pulp tissue (Mejàre & Cvek 1993, Barrieshi-Nusair & Qudeimat 2006, Chailertvanitkul *et al*. 2014). This, however, may represent a treatment step that is highly dependent on operator skills and equipment (e.g. a dental microscope). The dentine should carefully manipulated using sterile burs and sharp instruments, with a high speed bur and water-coolant used for pulp tissue removal (Granath *et al*. 1971), prior to disinfection and control of pulpal bleeding. Haemostasis and disinfection should be achieved using cotton pellets soaked ideally with sodium hypochlorite (0.5-5%) or chlorhexidine (0.2 to 2%). Although physiological saline has been the acceptable standard, it is limited by a lack of disinfection properties. If haemostasis cannot be controlled after 5 minutes, further pulp tissue should be removed (partial and full pulpotomy) and the wound surface rinsed as before. In cases with signs and symptoms of irreversible pulpitis, a full coronal pulpotomy can be carried out to the level of the root canal orifices with bleeding arrested as detailed previously. This procedure may be easier to

perform for GPs than a partial pulpotomy or even direct pulp capping. In all cases, a hydraulic calcium silicate cement should be placed directly onto the pulp tissue and the tooth definitively restored immediately to prevent further micro-leakage (Al-Hiyasat *et al*. 2006, Mente *et al*. 2010). If bleeding cannot be controlled after full pulpotomy, a pulpectomy and root canal treatment should be carried out.

Recommendation: Carious exposure of the pulp can be carefully treated with VPT in cases of asymptomatic or reversible pulpitis with a pulp cap (class II) or partial pulpotomy procedure. Full pulpotomy may be successful in cases of irreversible pulpits; however, better long-term prospective randomised data is required before this can be called the treatment of choice. All VPT procedures on the cariously exposed pulp should be carried out with the use of rubber dam, careful aseptic technique and antibacterial measures. For capping deep or extremely deep carious lesions the use of magnification is strongly recommended.

What materials should we use for VPT?

Calcium hydroxide has been the material of choice for IPC and pulpal application for many years (Glass & Zander 1949, Pitt Ford & Roberts 1991); however, it is limited by poor mechanical properties, absence of sealing properties (Browne *et al*. 1983) and incomplete hard tissue formation over the exposed pulp (Cox *et al*. 1987, Nair *et al*. 2008). Hydraulic calcium silicate materials, such as mineral trioxide aggregate (MTA), have demonstrated superior histological (Aeinehchi *et al*. 2003, Nair *et al*. 2008) and clinical outcome compared with calcium hydroxide in treatment of the exposed pulp (Cho *et al*. 2013, Hilton *et al*. 2013, Mente *et al*. 2014, Kundzina *et al*. 2017). Furthermore, there is evidence to suggest that calcium silicate cements can be used in IPC after deep caries removal (Leye Benoist *et al*. 2012, Petrou *et al.* 2014, Hashem *et al*. 2015), although longer-term clinical and radiographic follow up demonstrated no significant improvement compared with glass ionomer cements in terms of symptoms and pulp vitality (Hashem *et al*. 2018).

A range of hydraulic calcium silicate cements are available, which share similar biological properties, but exhibit chemical differences, which influences radiopacity, setting time and the potential to discolour the tooth (Parirokh *et al*. 2018). Resin-based composites and dentine-bonding agents have been investigated in VPT, but are now contraindicated due

to their cytotoxicity (Krifka *et al*. 2012), absence of mineral over the wound site and poor clinical outcome VPT (De Souza Costa *et al*. 2000). An open question thus relates directly to the procedure of one-stage selective caries removal is the choice of capping agent. If the remaining lesion is treated using a total bionding approach, it may arrest but remain radiolucent (Figure). It is not clear whether bioactive materials would improve this outcome. Further clinical research is necessary to find ways to avoid this problem.

Recommendations: After pulp capping, partial pulpotomy, or full pulpotomy the exposed pulp should be gently rinsed, disinfected, the bleeding controlled and a hydraulic calcium silicate material placed directly onto the exposed pulp. A calcium silicate material or glass ionomer should also be placed during IPC onto the residual soft dentine prior to definitive surface restoration.

How should I follow-up VPT cases and what is the expected prognosis?

VPT procedures should be assessed 6 and 12 months postoperatively and at regular intervals thereafter. The tooth should respond positively to pulp sensibility testing without a lingering or exaggerated response. It should be noted that certain teeth may not respond and that teeth, which have undergone full pulpotomy are expected to be unresponsive to testing. The patient should be free of pain and other symptoms and there should be radiological evidence of continued root formation in immature teeth as well as absence of signs of internal root resorption and apical periodontitis. Hard tissue formation over the exposure may be evident radiographically in some cases, but absent in others and therefore cannot be viewed as a necessary measure of success in the absence of other problems.

Permanent teeth with deep caries and mild symptoms indicative of no more than reversible pulpitis can be successfully treated by selective procedure as well as by IPC (Maltz *et al*. 2012, Hashem *et al*. 2015, 2018) and stepwise excavation (Bjørndal *et al*. 2010 & 2017), using a calcium silicate cement or glass ionomer to cover the soft dentine. Best evidence indicates that success, after a least one year and defined as absence of symptoms and maintenance of pulp vitality, is in the region of 70-90%, after selectively caries removal and avoidance of exposure (Bjørndal *et al*. 2010, Maltz *et al*. 2012, Hashem *et al*. 2015 , Bjørndal *et al*. 2017, Ali *et al.* 2018, Hashem *et al*. 2018). Equally, mature permanent teeth with caries

and symptoms no worse than reversible pulpitis, exposing the pulp and capping with a calcium silicate material, is also a predictable procedure; however, available data on the carious penetration depth was not well defined (Marques *et al*. 2015, Kundzina *et al*. 2017), and some of the sample material comprised mechanical exposures (Mente *et al*. 2014). Considering these limitations best current evidence would indicate that in this scenario a pulp capping procedure should be successful in approximately 80-90% (Hilton *et al.* 2013, Marques *et al*. 2015, Kundzina *et al*. 2017). However, in light of new materials and other developments, there is a need for high quality well-controlled research to determine the role of pulp exposure as a prognostic factor in the teeth with deep caries

A range of other factors may affect prognosis, in addition to accepted associations with patient symptoms, depth of caries and the material used. Prospective studies analysing the histological response to VPT materials invariably select young patients (Hörsted-Bindslev *et al.* 2003, Accorinte *et al*. 2008, Nair *et al*. 2008), as do clinical pulp capping and pulpotomy studies in carious teeth (Barrieshi-Nusair *et al.* 2006, Farsi *et al*. 2006, Chailertvanitkul *et al*. 2014, Taha *et al*. 2017). Young patients are selected due to an enhanced pulpal blood supply, open root apices and pulps free of age-related change (Goodis *et al*. 2012); however, patient age appears to not affect the outcome of VPT within more recent studies (Mente *et al*. 2010, Asgary *et al.* 2015, , Kunert *et al*. 2015, Kang *et al*. 2017, Linsuwanont *et al*. 2017). The size of the exposure site is also not a significant factor in success (Mejàre & Cvek 1993, Dammaschke *et al*. 2010), although one study suggested that if the exposure were large (>5 mm) it was less successful (Chailertvanitkul *et al*. 2014).

Recommendations: VPT should be carefully monitored by history, clinical and radiographic examination at 6 months, one year and at regular intervals thereafter. Thermal and electric pulp sensibility testing should be carried out where possible to monitor pulpal response. Stepwise excavation in adults is a predictable treatment to avoid pulp exposure, while, IPT and pulp capping can both be considered predictable treatments for the management of deep caries in permanent teeth. Notably, there is a shortage of long-term randomized data in this area, comparing which intervention that should be preferred.

Summary and concluding remarks

The recommendations contained in this ESE Position Statement are designed to assist clinicians in making decisions about the most appropriate treatments for their patients. Developments in understanding of the defensive response of the pulp-dentine complex and a drive to develop minimally invasive restorative solutions in endodontics have created significant interest in this area. The ESE welcomes these developments; however, it should be highlighted the there is a paucity of high quality comparative research on mature carious permanent teeth addressing many of the central questions. Although, this area is likely to modify in the future we must be remain cautious in recommending treatments of choice that are preliminary and not supported by robust long-term evidence.

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